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Procedures and Issues of a Restrictive Runway Configuration at Dallas/Fort Worth International Airport

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This paper documents the Dallas/Fort Worth operations in northwest flow including the transition to and from this configuration, to shed some light on issues needing further attention. Documenting pilot and air traffic controller decision logic during these transitions can be used to create realistic air traffic models. While the Dallas/Fort Worth airport is the main subject for this paper, delays are seen at any airport where a restrictive runway configuration used during periods of non-prevailing winds. The two main sources of data were the quantitative flight data from the terminal area and en route airspace regions and insights into the qualitative decision-making process provided by air traffic management subject matter experts. Archived flight data, such as aircraft tracks and landing runways, were used to plot aircraft approaches, holding patterns, and vectoring. As expected, the primary factor in causing delay was the reduced number of runways. Secondary factors such as reduced approach precision and a high air traffic controller workload arising from an uncommon runway configuration also contributed.

I. Introduction

ADVANCED air traffic research outlined in the Next Generation Air Transportation System (NextGen) plan, envisions safe, efficient, and reliable air travel at two to three times the current traffic levels.[1] With such high traffic volume it will be necessary for NextGen systems to be robust in the presence of off-nominal events that impact the National Airspace System (NAS). One such event that deserves attention occurs when an airport is forced into a restrictive runway configuration, such as the northwest runway configuration at Dallas/Fort Worth (DFW) airport. This configuration significantly restricts departure and arrival flow, because the number of available runways is decreased from seven to two. The dynamics of this local anomaly are different than other restricting events, such as transient convective weather or deicing situations. This condition typically occurs during clear days with a strong northwesterly wind when the surrounding NAS is operating at full capacity, as opposed to days where bad weather is restricting traffic over a broader region of airspace. The congestion affects not only the Terminal Radar Approach Control facility (TRACON) and the Air Route Traffic Control Center's (ARTCC) traffic management, but also the entire NAS.

As the traffic volume and delays have increased, so has the amount of research dedicated to increasing the arrival rate at airports. New methods for scheduling aircraft by weight class have been proposed.[2] The Surface Management System is being used to minimize delays of ground operations.[3] Recent work in the field of wake vortices show reduction in delays by optimizing arrival rates through the use of closely spaced parallel runways.[4] New advances in convective weather forecasting will allow improved en route flight planning, which will result in more planes reaching their destination on time.[5] These studies have all focused on standard airport operations, which are valid the majority of the time. Previous analysis of DFW airport arrival traffic has focused on a non-restrictive three runway configuration.[6] Most delay reduction research has been focused on nominal conditions and common problems, as they should be, but the rare situations which have equal impacts on arrival rates must not be overlooked.

The objective of this research is to study the impacts of a restrictive off-nominal airport configuration in order to understand the conditions leading to it and the factors used in the timing of the configuration change. A restrictive runway configuration not only causes delays, but also has safety impacts when transitioning between configurations.

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This paper documents the airport operations in north and northwest flow including the transition to and from the latter configuration. Documenting pilot and traffic controller decision logic in these situations reveals delay causing factors other than the restrictive runway configuration. Although DFW is the main subject of study for this paper, delays are seen at any airport where a restrictive runway configuration used during periods of non-prevailing winds. While several days were used, two main case days will be presented in this study. The first, February 24th, 2007, was chosen because the winds alone were responsible for shutting down the airport. The second, March 20th, 2006, was selected because it clearly shows the delays accrued after operating in a restrictive runway configuration.

II. The Dallas/Fort Worth International Airport

Figure 1 is a chart of the DFW terminal environment. DFW TRACON utilizes a 4 corner post airspace design. Departing aircraft leave the airspace to the north, south, east, or west, as noted by the striped arrows. Arriving aircraft enter DFW airspace from the corners, indicated by the checkered arrows. Navigational fixes, called corner posts, have been established at each corner where arriving aircraft pass en-route to DFW, mapped by the four labeled dots. At the TRACON boundary are multiple meter fixes, indicated by the diamonds. Meter fixes represent the handoff point between the ARTCC and the TRACON. During high volume operation, the rate at which aircraft are delivered to the TRACON airspace may be restricted, or metered. When metering is in effect, the meter fixes become Controlled Time of Arrival (CTA) fixes and arriving aircraft cross the fixes at scheduled times to provide adequate spacing at the runway threshold. The spacing between the aircraft depends on of the type of aircraft and runway conditions. Table 1 shows the minimum in-trail separations required for landings, i.e., runway threshold crossings, for dry runways.[7]

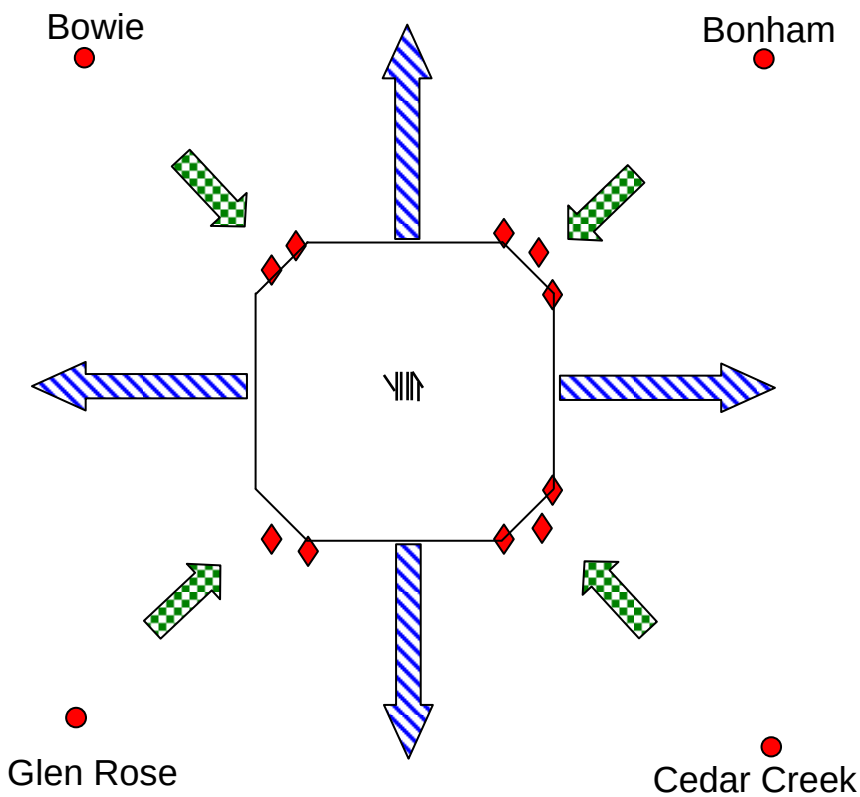

Figure 1. DFW TRACON arrival and departure corridors.
Corner posts are shown as dots and meter fixes as diamonds.

Table 1. Minimum in-trail separation (nm) for dry runways

Leading Aircraft	Trailing Aircraft			
	Small	Large	B757	Heavy
Small	2.5	2.5	2.5	2.5
Large	4	2.5	2.5	2.5
B757	5	4	4	4
Heavy	6	5	5	4

With respect to arriving aircraft, the controller's goal is to land the aircraft as quickly as possible while maintaining the required minimum separation for safety. When the arrival rate is unrestricted, the separation distance between aircraft may be larger than the minimum because of the low air-traffic density. When the number of aircraft arriving exceeds the limits of the runways, the ARTCC will begin metering

to ensure the minimum separations are maintained. The TRACON controller's task of merging multiple streams of arriving aircraft is made more difficult when different aircraft types requiring different in-trail separation are mixed together.

The airport's five north/south oriented runways were designed with the prevailing north and south winds in mind. The two remaining northwest oriented runways are used, in combination with the north/south runways, in light to no-wind conditions or used exclusively when the rare northwesterly wind is strong enough to force the pilots' abandonment of the north/south runways.

III. Difference in Approach Procedures for North and Northwest Flow

The north flow configurations are used about 30% of the time while the south flow configurations use most of the remaining 70%. Northwest flow is a separate configuration from the north and south which is only used a few times a year. During a north-four configuration (N4), DFW will utilize six out of its seven runways. Figure 2 is illustrates these points. The standard procedure is to use the two inboard runways, 36R and 35L, for departures and runways, 36L, 35C, and 31R for arrivals. Runway 35R will be used as the traffic load increases, but it is less desirable because of its distance from the airport terminals and the additional runway crossing that is required. The general rule-of-thumb calls for easterly arrivals to use 35C and westerly arrivals to use 36L. There are, of course, exceptions to the rule depending on weather and traffic density. If, during light traffic, an arrival from the east has a terminal facing the west, the controller may approve pilot's request for landing on runway 36L. A clear example of the relationship between the controllers/pilots and runway assignment can be seen in the standard north flow day of January 1st, 2007. Just over 100 aircraft, originally scheduled to land on the two main outboard runways, landed on the two inboard runways (36R and 35L).

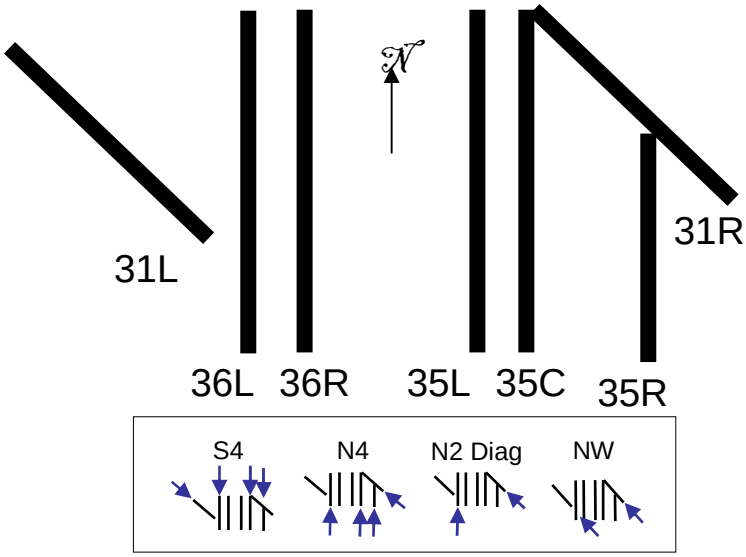

Figure 2. Runway Layout at DFW airport. *Airport configurations show runways used by arriving aircraft.*

While in the northwest configuration, the final approach for runway 31R is a standard, straight ILS lineup from the southeast. The final approach for runway 31L begins by intercepting the localizer for runway 35R, then a turn is made for a bearing of 312°, straight for runway 31L.[12] Figure 3 illustrates this procedure. During visual conditions, both diagonal runways are used in the northwest configuration; but in instrument conditions only 31R is used. When the airport is only using 31R, because of poor visibility and northwest winds, it is in its most restrictive configuration with only one runway available for arrivals.

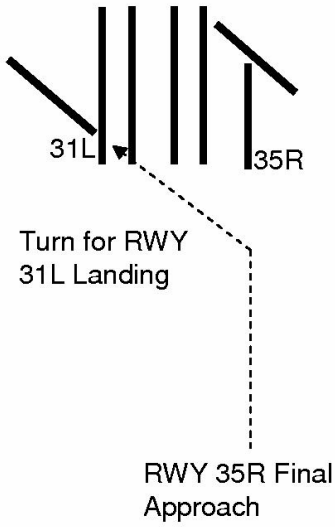

Figure 3. Final approach for runway 31L

IV. Conditions for Entering Northwest Flow

In the northwest configuration at DFW, there are two competing pressures at work with the Traffic Management Unit (TMU) in the middle. The NAS wants to spend as little time as possible in this configuration because it reduces capacity. However, the pilots may prefer a northwest landing because a lower crosswind component is encountered. The TMU is striving for predictability, they would rather operate in the restrictive northwest configuration than have multiple go-arounds due to high crosswinds is a north 3 configuration. When arrival traffic becomes unpredictable the chances for operations errors increase and safety becomes a concern. Obviously, the northwest configuration is preferred when the wind is from the northwest, but what combination of wind speed and direction is needed to make the switch? The answer is difficult to quantify because of the heavily weighted human factors used in making the decision. The effect of light winds (less than 10 kts) on an aircraft is negligible, rendering the wind direction irrelevant. Only when the crosswind component (the magnitude of the wind times the sine of the crosswind angle) across the runway is above some limit will the pilot request another runway. Aircraft are certified with a maximum demonstrated crosswind component; but pilots, given the opportunity to mitigate their risk, will almost always choose an alternate runway before the maximum crosswind has been reached. Figure 4 shows a graphical representation of the wind speed/crosswind angle relationship. Most aircraft will land easily with a crosswind component of 20kts or less. Between 20 and 35kts of crosswind other measurable factors including aircraft type, wind gust speed, and condition of the runway surface will start to impact the ability of some aircraft to land. Crosswinds above 35kts will generally prohibit all aircraft from landing. The exact value of the boundary between the safe and unsafe landing conditions is unknown because of the uncertainty introduced by the human experience level, familiarity with the airport, and the pilot's 'gut feeling.' [8,9]

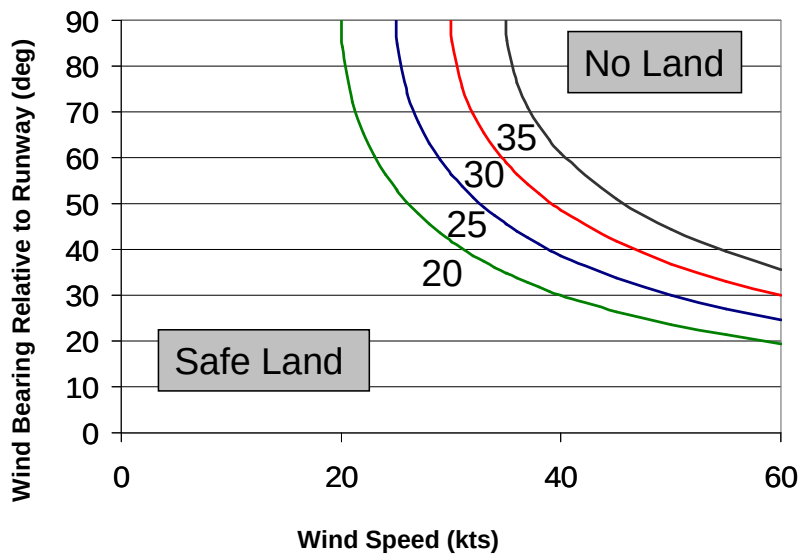

Figure 4. Impact of crosswind on ability to safely land. *Plotted lines represent the crosswind component across the runway in knots.*

One interesting question that arises with regards to the human decision factors is how much more crosswind would a pilot land in if he/she did not have the option of another runway? The majority of the Operational Evolution Partnership (OEP) airports have runways to accommodate off-nominal wind conditions that make the main runways undesirable.[10] The OEP consists of 35 airports across the U.S. which handle 70% of all passengers. Six OEP airports have only parallel runway layouts giving the pilot only two options: to land or not to land. Seattle/Tacoma (Sea-Tac) is one such airport. On December 14, 2006, a northwest flight had to make a second attempt, with the first one called off after the main landing gear touched down. Severe unstable rolling due to high gusty crosswinds occurred just before touchdown and continued briefly after the plane left the tarmac. On the second attempt similar rolling developed but the pilot was able to complete the landing.[11] Both DFW and Sea-Tac experience delays during adverse wind conditions, one for a reduced number of usable runways and the other because of an increase in landing difficulty. At DFW the runway switch is made before aircraft are forced to make risky crosswind landings on the north/south runways. Making the switch to the northwest runway sooner, compromises the traffic flow, while making it later increases the difficulty in the landings. With so many factors involved in this decision, finding the optimal switching time is challenging.

DFW airport will continue to use its north/south runways until a pilot or the TRACON requests the northwest configuration from the control tower, which has the ultimate authority in runway configurations. Most pilots of like aircraft exhibit a follow-the-leader type behavior; once one pilot calls for a northwest landing, the subsequent arrivals will generally be content to land on a northwest orientated runway. The traffic managers are familiar with

this procedure, so after a few northwest requests they switch the runway configuration. The ease of changing a runway configuration depends on the amount of traffic at that time. If an experienced traffic manager foresees the weather favoring the northwest configuration, he/she may, depending on the traffic situation, switch the configuration before the pilots request it. Air traffic managers prefer switching configurations during lulls as opposed to rushes, even if there are fewer available runways after the switch, in order to make the runway change as seamless as possible from a traffic flow perspective.

When the wind abruptly changes direction, the runway configuration will change directly from north or south parallel runways to the northwest configuration. However, when a large weather system enters the area and changes the wind bearing from south to northwest over several hours, an intermediate configuration may be used. The north 2 diagonal and north 3 diagonal both utilize the 31R diagonal runway as well as one or two north runways, respectively. These multidirectional configurations give the pilots the choice of landing direction when the crosswind component across the north/south runways falls somewhere between the safe landing and no landing areas in Fig. 4.

V. Case Day 1: February 24th, 2007

This day was chosen because the winds alone were responsible for stopping all traffic at the airport. On February 24, 2007, the traffic management unit logs for the Fort Worth ATRCC show an airline advisory for crosswind limits based on aircraft type. The following list pairs classes of aircraft with their maximum crosswind landing components, as specified by the command center log: regional jets – 25kts, 757/767 – 29kts, and 737 – 35kts. This defines a transitional region between 25 and 35kts of crosswind where some aircraft should be landing north and others should be landing northwest. Figure 5 shows the runway configurations for DFW on the day of February 24, 2007. The archived wind speed and bearing data used in this study are recorded once every hour. The wind data at the time of a runway configuration change have been approximated based on the previous and successive wind records. Once the wind bearing begins shifting to the northwest and the wind speed is large enough to produce a crosswind component of 25 to 29kts, the runway configuration is changed, from south 4 to north 2 diagonal, to allow both north and northwest landings. Ironically, soon after the switch the wind bearing shifted back southward,

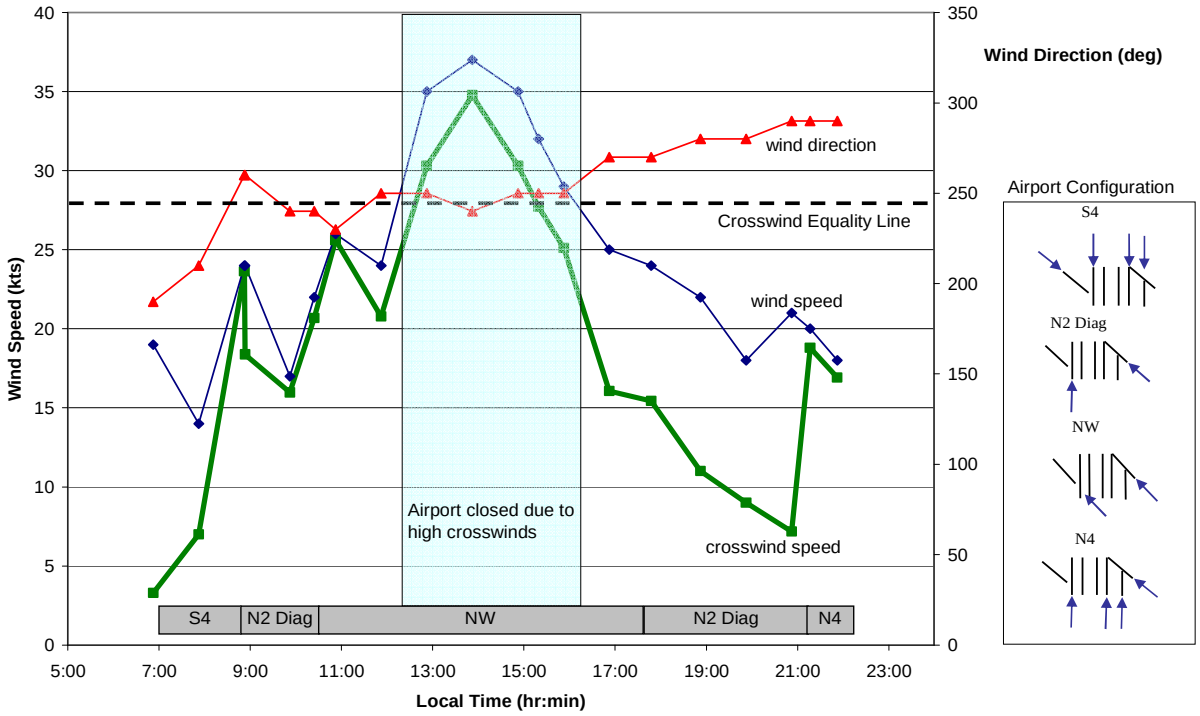

Figure 5. Crosswind data and runway configurations for Feb. 24, 2007. *Crosswind and wind speed use the left axis, while the wind direction and crosswind equality line use the right axis. Wind directions above the crosswind equality line produce less crosswind across the northwest runways, while winds below the line produce less crosswind across the south runways. Airport configurations show runways used by arriving aircraft.*

increasing the crosswind component on the northwest runways. By 11:15A.M., three arrivals performed go-arounds due to wind shear. After 12:00P.M., most arriving aircraft had diverted to other airports due to the wind gusts up to 40kts. Peak wind gusts were recorded at 47kts. The Air Traffic Control System Command Center (ATCSCC) and Traffic Management Unit (TMU) logs show that both facilities anticipated problems due to winds 4-6 hours in advance. The traffic managers knew the winds would stop all arrivals, but they were still willing to let each pilot in holding patterns around the airport make the decision to land or divert for themselves before all airport traffic was fully stopped due to winds. This is a clear example of how much weight the pilots' decisions carry.

The crosswind was calculated using the north runways for the S4 and N4 configurations and the northwest runways for the N2 Diagonal and NW configurations. The wind direction line and the crosswind equality line (wind direction of 245°) both use the right-hand axis. All wind direction data points that fall below the equality line will produce a smaller crosswind component for a southward landing and data points above the line will produce a smaller crosswind component during northwestward landings.[13] From 10:00 to 16:00 local time the wind bearing jumps back and forth across the 245° line nullifying any benefits made by switching from a south to a northwest landing. Based on the data and hindsight, it may have been better to remain in the S4 configuration until the 14:00 hour, but at the time the decision was made the wind bearing was predicted to increase and the northwest configuration was the best choice. It is important to note that the wind speed and direction alone were responsible for stopping traffic at the airport. Prior to its closing, visibility was consistently between 7 and 10 statute miles and there were no convective weather systems in the area.

Figure 6 shows the various measures of delay and runway configuration changes for February 24, 2007. The average and maximum delays are calculated by taking the difference between actual and planned meter fix crossing time for arriving aircraft; these measures do not include diverted aircraft delays. The Delay Reporting System (DRS) includes the delays incurred by both arrivals and diverted aircraft. The DRS records maximum delays in 15 minute increments. As the crosswind component increases (see Fig. 5), the average delay rises and peaks at the 11:00 hour. Through the next hour, many arrivals started diverting to surrounding airports, causing a shift in the delays from DFW meter fixes to diversion airports. While DFW traffic was stopped, due to the high winds, all the accrued delays came from diverted aircraft. The delays begin to decrease after the 20:00 hour partially due to both calming winds and a lighter traffic load as the day winds down. Figure 6 gives a clear picture of the delays caused by a restrictive runway configuration and high crosswinds.

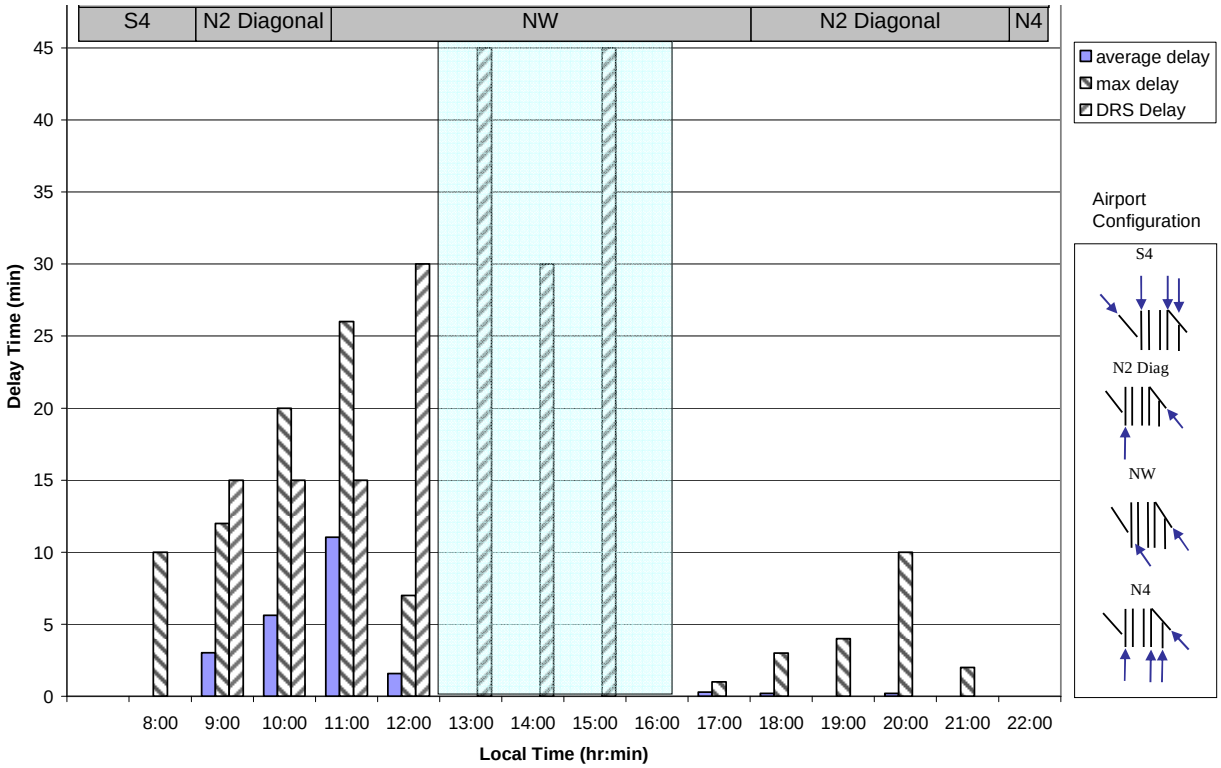

Figure 6. Delay data and runway configurations for February 24, 2007. *The shaded area represents the airport closure due to high crosswinds.*

VI. Case Day 2: March 20th, 2006

March 20th, 2006 was chosen to illustrate the delays caused by a restricted airport expected to operate at full capacity. On this day DFW experienced a strong northwesterly wind causing the airport to use the NW runway configuration. Other configurations were also used on this day. Any time the wind direction would allow the use of the north-3 (N3) configuration, the controllers would make the switch in order to ease the delays caused by the more restrictive format. From the early morning hours of 6:00 to 10:00, local time, the airport used the N3 configuration. Then in the evening, from roughly 20:00 onward, DFW was constricted by an unyielding northwest wind.

Figures 7 and 8 are the aircraft track plots for these two time periods, respectively. The tracks in the N3 configuration plot are organized with few holding patterns being performed at the corner posts. Once the aircraft pass the meter fixes they follow a structured flight path to the runways. The limited use of holding patterns and vectoring indicates the number of available runways meets the demand by the arriving aircraft. When in the northwest configuration, the demand for landing runways exceeds the supply and causes bottleneck congestion for arriving aircraft. For this reason, Fig. 8 appears to be less structured with various holding patterns and spacing maneuvers occurring between the meter fixes and the airport. The northwest flow configuration requires a high work load from the air traffic controllers as they attempt to merge streams of aircraft for three runways down to two.

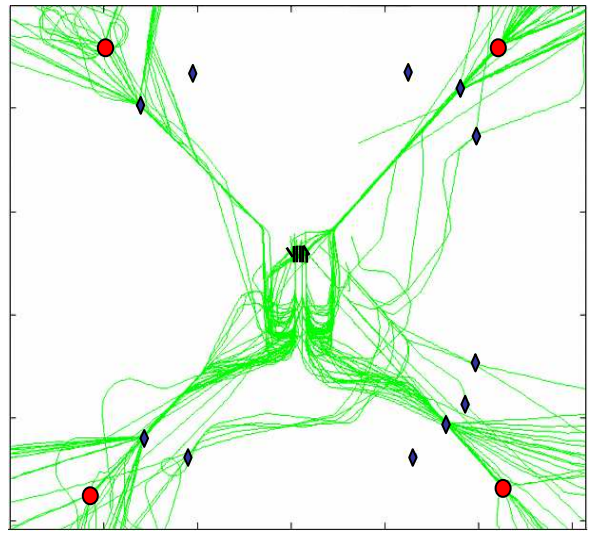

Figure 7. North 3 arrival flow at DFW on the 20th of March 2006. *Corner posts are shown as dots and meter fixes as diamonds; DFW runways are located at the center of the figure.*

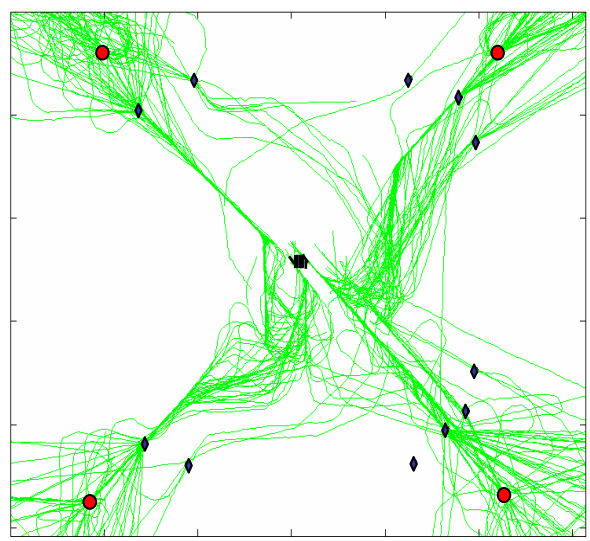

Figure 8. Northwest arrival flow at DFW on the 20th of March 2006. *Corner posts are shown as dots and meter fixes as diamonds; DFW runways are located at the center of the figure.*

Figure 9 (next page) shows the delays on March 20 and how sensitive they are to runway configurations. The first half of the day shows the average delay hovering around zero. As the winds shifted direction and the airport changed to a northwest configuration the delays began to increase significantly and abruptly. It was not until the natural subsiding of the day's arrivals that the delays started to decrease. In the N3 and S3 parallel configuration, three runways are reserved for arrivals and two different runways are used for departures. In the northwest configuration, departing pilots may request to take off from a diagonal runway instead of a north/south runway. Sharing only two runways between arrivals and departures is a large contributing factor to the delays and causes increased miles-in-trail between arrivals.

While there are many reasons for aircraft delays, such as traffic density, weather conditions, human experience levels and errors, it is clear that runway configuration is an important factor. The most obvious cause for delay during the northwest configuration is the reduced number of runways, but there are also other minor causes. The number of variables makes pinpointing the minor delay contributions from any one factor difficult. Despite this, the approach patterns in Fig. 7 are more defined than those in Fig. 8. This suggests that the N3 approaches are more structured and preplanned than those of the NW flow. This would make sense because the N3 is a common configuration while the NW only occurs a few times a year. Table 2 shows the dates and durations of the NW configuration recorded by the Center TRACON Automation System (CTAS) Traffic Management Advisor (TMA).

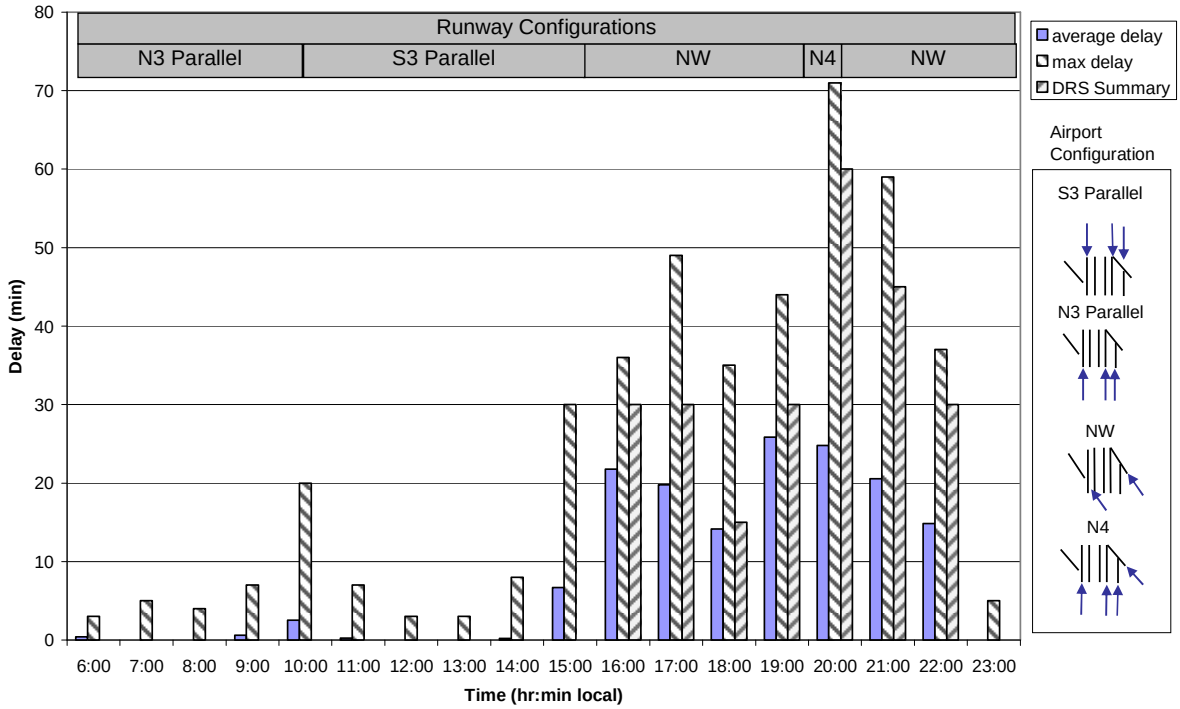

Figure 9. Delay data and runway configurations for March 20, 2006

The predominant opinion from the traffic controllers is that DFW is configured for NW flow 4-6 times a year. Data collected from CTAS for the current and previous years support this claim. However, there were no NW configurations recorded for the following years: 1999, 2000, 2002, 2004, and 2005. After further investigation it was found that CTAS only records the runway configurations when they are entered by the TMU. As CTAS is an advisory tool for the TMU, there is no hard requirement that it must be changed to reflect the current runway configuration. This would account for the errors in the CTAS data used in this study. The recent increases in CTAS-recorded northwest configurations indicates that the TMU is now using CTAS more in non-typical situations than they have in the past.

One example of an unrecorded northwest flow configuration occurred on November 11, 2005. The wind conditions were ideal for the northwest flow (30kts gusting to 38kts at a bearing of 260-270°), but CTAS was in a north-2 diagonal instead of northwest. The north-2 diagonal is a configuration with two runways, one north and one northwest. Without knowing exactly how the configurations are defined, north-2 diagonal could easily be misinterpreted as the two northwest diagonal runways. Despite CTAS running in with north-2 diagonal, the traffic was landing on both diagonal runways.

Table 2. DFW NW Runway Configuration Data Recorded by CTAS

2007		2006		2003		2001	
Date	Duration (hr.min)	Date	Duration (hr.min)	Date	Duration (hr.min)	Date	Duration (hr.min)
13-Feb	0.24	12-Feb	0.49	23-Feb	3.19	15-Mar	6.19
24-Feb	7.21	9-Mar	6.18	9-Dec	6.02		
1-Mar	2.00	20-Mar	8.58	10-Dec	9.22		
14-Apr	1.48	7-Apr	3.03				
		27-Oct	7.33				
		15-Nov	11.49				

VII. Summary

This paper was a first step towards understanding the operational impacts of an unusually restrictive airport configuration with regards to delay and safety. At DFW airport, delays accrued in the northwest runway configuration are mainly a result of limited runway capacity. The high demand for a limited supply of available runways leads to severe congestion and high work loads for air traffic controllers. Human decisions made during the transitional process into the northwest configuration introduce another degree of uncertainty in determining when change will occur because of the individual differences of the personnel involved. Logic used by both the air traffic managers and pilots concerning runway configuration changes has been documented, but more research in this area needs to be done to determine whether or not the decision logic can be standardized. Highly structured final approaches are used in nominal runway configurations, but in a restrictive runway configuration additional spacing maneuvers are performed by arriving aircraft between meter fixes and final approach fixes. Time spent in the restrictive runway configuration should be minimized, but further means of delay reduction may be found in solidifying decision logic and stabilizing off-nominal final approaches.

Acknowledgments

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